Sustainability Cycles in China, India, and the World?

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Abstract
This paper studies the key variables of the so-called ImPACT identity, which includes four drivers of environmental impact (Im): population (P), affluence (A), intensity of consumption (C), and technology (T). In the empirical analysis, carbon dioxide emissions from fuel combustion (CO_2) represents the environmental impact, and the influencing factors are represented by the amount of population (POP), gross domestic product per capita (GDP/POP), energy intensity of the national economy (TPES/GDP), and carbon intensity of energy supply (CO_2/TPES), respectively. The authors present annual changes in the ImPACT variables and their comparative analysis in the World, China, and India during the time period 1971-2009. They also identify the cyclical nature of annual changes in the ImPACT variables, similar to the Goodwin growth cycle model. In the formation of green growth strategies this kind of empirical finding must be taken seriously into consideration.

Keywords: ImPACT analysis, China, India, the World, global sustainable development, economic growth, economic cycles, economic planning, history of global economy

JEL classification: O11, N11, N90, O210

Introduction

We have known for a long time that economic growth, population, and technological development are crucial variables when we discuss about the sustainability of World development. The nature of these interactions is highly complex and environmental problems cannot be ascribed to any single cause, such as "growth mania," "careless technology," or "population explosion" (Waggoner & Ausubel, 2002; cf. Olsson, Hourcade & Köhler, 2014).

There are many dynamic interactions between these key variables. An empirical study of these variables of sustainable development can provide some useful information for the planning of sustainable development in the World. In this article we analyze changes in sustainability towards a less or more sustainable direction. There are many uncertainties related to climate change and related socio-economic dynamics. Such uncertainties are linked to monitoring systems, cost estimates, ecosystem services, and impacts.

Climate scientists have established the human causes of climate change. The existing patterns of economic development remain closely associated with increased energy demands and rising fossil fuel use. In this article we argue that, in the field of global sustainability analyses, we too often underestimate the possibility of cyclical economic development phenomena. There are various cycles in economic development and we should analyse how these are linked to sustainability processes. In this article we shall focus on the classical ImPACT approach and reveal the potentially cyclical nature of key dynamic variables of ImPACT equation. Understanding the cyclical nature of sustainability problems can open new avenues to sustainability policy and planning in the global governance.

Material and Methods

In this article, one scientific challenge is to analyse these basic issues with empirical basic data. The dynamic relationships of ImPACT variables (Impact, Population, Affluence, Consumption, and Technology) is surely a relevant policy issue for global decision-makers and other stakeholders. We can expect that better understanding of ImPACT dynamics can help us to reflect on the precautionary principle in a better way.

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On the basis of our ImPACT analysis it is possible to identify extreme economic conditions (zones) and turning points of sustainable development in the global setting as well as within a given country and to inform decision-makers in a better way. We can also note that historically the socio-economic needs to use the precautionary principle vary. These equations constitute the basic methodological framework of our analysis. This kind of methodological approach is very generic and allows comparative sustainability analyses in the global setting. Climate change mitigation may have to focus on greenhouse gases like CO_2 emissions and on the potential role of biomass, among others, as a carbon sink. Population is still growing in many developing countries and scaling up the environmental impact. Population issues and growing affluence must be considered when discussing emission reductions.

Climate policy has only very recently had an influence on emissions, and strong political actions like changing energy mix and economic structures are now called for climate change mitigation. Environmental policies in general must cover all the regions and countries related to production and environmental impacts in order to avoid outsourcing of emissions and harmful leakage effects. The key idea of our analysis is that the macro-level drivers affecting changes in emissions can be identified with the ImPACT framework. Statistics for generally known macro-indicators are currently relatively well available for different countries and regions, and the method is extremely transparent, which increases the usability of the methodological framework. Using transparent macro-level figures and a simple top-down approach are also appropriate decisions in evaluating and setting international emission reduction targets. In the basic form of the ImPACT model, the economic intensity of consumption as well as the emission intensity of use are both included. A similar methodological framework has seen to be useful in many other studies (Saikku, 2009).

This article is focused on global trends of sustainability in relative terms. We focus at the global level on the World, China, and India. So our analysis covers the whole World with these three major regions. We have selected these regions, because they are going to be in key strategic roles in the global climate policy in the future. This kind of global analysis helps us understand where World development is going nowadays. Our approach can provide realistic situation analyses for global decision-makers.

The analysis we provide in this article is also relevant for sustainable development policy, energy policy and global climate change policy. Our empirical analysis covers the years 1971-2009, due to some data limitations. This means that we mostly analyze global developments after the first oil crisis period. We use a method which is widely used for scientific analyses. The method is based on IPAT identity. This method was introduced by Ehrlich and Holdren (1971) and Commoner (1972). In the IPAT identity, the forces of population (P), affluence (A), and technology (T) cause an impact (I). A developed version of the IPAT model is the ImPACT model, which we use as a methodological starting point in this article (cf. Schulze, 2002).

As we have noted, ImPACT model refers to a formula developed to describe the impact of human activity on the environment. This model describes how growing population, affluence, consumption, and technology contribute toward our environmental impact. This article is based on this basic ImPACT approach and framework. The classical Kaya identity approach is closely related to this approach (Meyerson, 1998; Kaya, 1990; Kaya & Yokobori, 1997).

We have known for a long time that economic growth, population, and technological development are crucial variables when we discuss about sustainability of World development. The nature of these interactions is highly complex and environmental problems cannot be ascribed to any single cause, such as “growth mania,” “careless technology,” or “population explosion” (Waggoner & Ausubel, 2002; James, 1978; Taylor, 1996; Halsnas, Markandya & Shukla, 2011). There are dynamic interactions between these key variables. A study of these variables of sustainable development can provide some useful information for the planning of sustainable development in the World. In this article we analyze changes in sustainability towards a less or more sustainable direction.

The discussion about the Stern report indicates that there are many uncertainties related to climate change and related socio-economic dynamics (Stern, 2007). Such uncertainties are linked to monitoring systems, cost estimates, ecosystem services, and impacts. In this article, one scientific challenge is to analyse these basic issues with empirical basic data. The dynamic relationships of ImPACT variables are surely a relevant policy issue for global decision-makers. We can expect that better understanding of the ImPACT dynamics can help us to reflect on

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the precautionary principle in a better way (Arrow & Fisher, 1974; Epstein, 1980; Sunstein, 2005).

The article is organized in the following way. First, we present the ImPACT identity and associated methodological framework. Secondly, we present key changes in the variables of the ImPACT identity in the World, China, and India. Thirdly, we present a comparative analysis of the ImPACT variables in the World, China, and India. Fourthly, we report the identified ImPACT cycles in the World, in China, and in India. Fifthly, we summarize our key findings, emphasizing World scale developments.

Theory and Calculation: The imPACT Identity and Methodological Framework

In this study, we use the conventional methodological ImPACT approach to study key sustainability trends. It shows how contributing factors compound to produce a total effect. This approach is important in analyzing changes. This approach also allows assignment of blame or praise to important factors. The ImPACT methodological approach selected in this study guides access for policy and action (Herendeen, 1998).

In many economic studies the role of population for economic growth process has been discussed. How does economic growth affect the natural environment? The ImPACT model provides one methodology to analyze this fundamental development issue.

Typically, environmental economists such as Perman & McGilvray (1996), have thought that to the extent that economic growth involves an increase in material and energy inputs, the potential for adverse environmental impacts is greater. In a World in which no input substitution is possible, the materials balance principle demonstrates that material and energy throughputs are proportionate to the level of economic activity, and so growth inevitably results in deteriorating environmental conditions. The growth process is characterized by quantitative changes and substitution effects. In some cases higher economic value may not require higher quantities of inputs.

ImPACT statistics nicely verify this basic economic learning. For example, consumed energy inputs do not lead to similar economic growth. There are no fixed coefficients between the ImPACT variables; instead, they are flexible depending on current economic cycles. In the sustainability analyses, so-called U-curve-hypothesis (the Environmental Kuznets Curve hypothesis) and N-curve hypothesis have been used in many empirical studies to analyse the relationship between economic growth and environmental pressures (see e.g. Perman & Gilvray, 1996; Dinda, 2004; Vehmas, Kaivo-oja & Luukkanen, 2007). These economic dynamics models of environmental pressures lead us to believe that countries and regions are linearly following some kind of a "railway hypothesis".

One methodological benefit of the ImPACT-model is that it helps us to imagine the potentially cyclical nature of the sustainability puzzle. Relative scarcities, changing consumer preferences, technical substitution possibilities, and changing coefficients are probably behind cyclical changes in many economies (see e.g. Figueroa & Pasten, 2013). These basic microeconomic factors lead economies to the cycles of development which were observed in the macroeconomic framework of Goodwin's growth cycle model (see e.g. Marglin, 1984; Goodwin & Punzo, 1987; Marglin & Bhaduri, 1988; Skott, 1989).

In the ImPACT identity, total environmental impact (I) is determined as the product of four drivers: population (P), affluence (A), consumers' intensity of use (C), and level of technology (T) (see e.g. Waggoner & Ausubel, 2002; DeHart & Soulé, 2000; Chertow, 2001):

$$I = P \times A \times C \times T, \qquad (1)$$

where the variable I is CO_2 emissions from fuel combustion, P the amount of population, A gross domestic product (GDP) per capita, C primary energy intensity of GDP, and variable T is the carbon dioxide intensity of primary energy use. Lowercase letters (p, a, c, and t) represent the annual percentage changes of four key drivers, which add up to the change of impact (i).

$$i = p + a + c + t \qquad (2)$$

The identity dissects the contribution by each of the four drivers to changing the impact, up or down. In this ImPACT identity environmental impact is the driven variable. Attributes of CO_2 emissions and variables that cause them, are state variables (Table 1).

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Table 1. Variables of ImPACT Identity.

Table 1.

Variables of the ImPACT identity. Attributes of CO_2 emissions and variables that cause them.

Symbol	Attribute	Dimension
State variables		
I	Impact	CO_2 emissions, tonnes
P	Population	Number of population
A	Affluence	GDP per capita, dollars
C	Consumption	Energy use for GDP production, toe per dollar
T	Technology	CO_2 intensity of energy use, tonnes per Mtoe
Rates of change		
i	change in CO_2 emissions	% per year
p	change in population	% per year
a	change in affluence	% per year
c	change in consumption	% per year
t	change in technology	% per year

With using the attributes described in Table 1, Equation 2 can be rewritten as follows:

$$CO2 = POP \times \frac{GDP}{POP} \times \frac{TPES}{GDP} \times \frac{CO2}{TPES} \qquad (3)$$

This equation describes the production side of the economy, and therefore C refers to energy consumption in order to produce the gross domestic product (GDP). From the point of view of the environmental impact, the selected variable (total primary energy supply or TPES) is the most relevant one because it covers all fossil fuel combustion processes which cause CO_2 emissions.

In this study, a logarithmic "decomposition" approach will be used. This approach has been used in various energy and climate change analyses (e.g. Saikku, 2009, 2010; Saikku, Rautiainen & Kauppi, 2008). Change variables (i, p, a, c, and t) are defined in the following way by applying a three year moving average:

$$\mathrm{i} = \frac{ln\left(\frac{1}{3}\ \sum_{j=n-2}^{n} CO2_j\right) - ln\left(\frac{1}{3}\sum_{k=1}^{3} CO2_k\right)}{n-2} \quad (4)$$

where n is the length of the studied time period (in this case 39 years). Respectively, the formulae for the average annual rates of change in the components p, a, c, and t are:

$$p = \frac{\ln\left(\frac{1}{3}\ \sum_{j=n-2}^{n} POP_j\right) - \ln\frac{1}{3}\left(\sum_{k=1}^{3} POP_j\right)}{n-2} \quad (5)$$

$$a = \frac{\ln\left(\frac{1}{3}\ \sum_{I=n-2}^{n} \mathrm{GDP}_I \ / \ \frac{1}{3}\sum_{j=n-2}^{n} P_j\right) - \ln\left(\frac{1}{3}\ \sum_{m=1}^{3} \mathrm{GDP}_m \ / \ \frac{1}{3}\sum_{k=1}^{3} P_k\right)}{n-2} \quad (6)$$

$$c = \frac{\ln\left(\frac{1}{3}\ \sum_{I=n-2}^{n} \mathrm{TPES}_I \ / \ \frac{1}{3}\sum_{j=n-2}^{n} GDP_j\right) - \ln\left(\frac{1}{3}\sum_{m=1}^{3} \mathrm{TPES}_m \ / \ \frac{1}{3}\sum_{k=1}^{3} GDP_k\right)}{n-2} \quad (7)$$

$$t = \frac{\ln\left(\frac{1}{3}\ \sum_{I=n-2}^{n} CO2_I \ / \ \frac{1}{3}\sum_{j=n-2}^{n} TPES_j\right) - \ln\left(\frac{1}{3}\sum_{m=1}^{3} CO2_\mathrm{m} \ / \ \frac{1}{3}\sum_{k=1}^{3} TPES_k\right)}{n-2} \quad (8)$$

These equations constitute the methodological framework of our analysis. This kind of methodological approach is very generic and allows comparative sustainability analyses in the global setting. Climate change mitigation may have to focus on greenhouse gases like CO_2 emissions and on the potential role of biomass, among others, as a carbon sink. Population is still growing in many developing countries and scaling up the environmental impact. Population issues and growing affluence must be considered when discussing emission reductions (see e.g. Meyerson, 1998; Kaya, 1990; Sunstein 2005; Commoner, 1972).

Climate policy has only very recently had an influence on emissions, and strong political actions like changing energy mix and economic structures are now called for climate change mitigation. Environmental policies in general must cover all the regions and countries related to production and environmental impacts in order to avoid outsourcing of emissions and harmful leakage effects. The key idea of our analysis is that the macro-level drivers affecting changes in emissions can be identified with the ImPACT framework. Statistics for generally known macro-indicators are currently relatively well available for different countries, and the method is extremely transparent which increases the usability of the methodological framework. Using transparent macro-level figures and a simple top-down approach are also appropriate in evaluating and setting international emission reduction targets. The basic form of the ImPACT model includes the economic intensity of consumption and emission intensity of use. Similar kind of methodological framework has been seen useful in many other studies (see e.g. Saikku, 2009; Schulze, 2002; And & Zhang, 2000; Zhang, 2000; Paupach et al, 2007; Saikku, Rautiainen & Kauppi, 2008; Saikku, 2010).

Changes in the ImPACT Variables in the World, China and India: comparative analysis

In this section the analysis of changes in key variables of sustainable development in the World, China, and India will be presented by looking at annual percentage changes in the ImPACT variables, both basic variables (CO_2, TPES, GDP, and POP) and the variables defined in the ImPACT identity, calculated with the method described above. Figures 1-3 show indexed trends (1971=100) of the basic variables, carbon dioxide emissions from fuel combustion (CO_2), total primary energy supply (TPES), gross domestic product (GDP), and population (POP) in the World, China, and India, respectively.

After the two oil crises in the 1970s, the growth rates of all key variables except population dropped at the global level, but came up soon after both crises. However, CO_2 emissions from fuel combustion and total primary energy supply decreased also in absolute terms. Similar periods of decreasing growth rates took place also in the recession of the early 1990s and late 2000s. In general, there seems to be a strong positive correlation between CO_2 emissions from fuel combustion and primary energy supply (TPES), but GDP growth has been much faster. At the global level, there is a sign of weak decoupling between GDP and both TPES and CO_2 emissions (Fig. 1). The long-run trend of population growth has been quite linear, so the annual growth rate has been decreasing. However, the World population is still growing in absolute terms in recent years with an approximate rate at one per cent per year (Fig. 1).

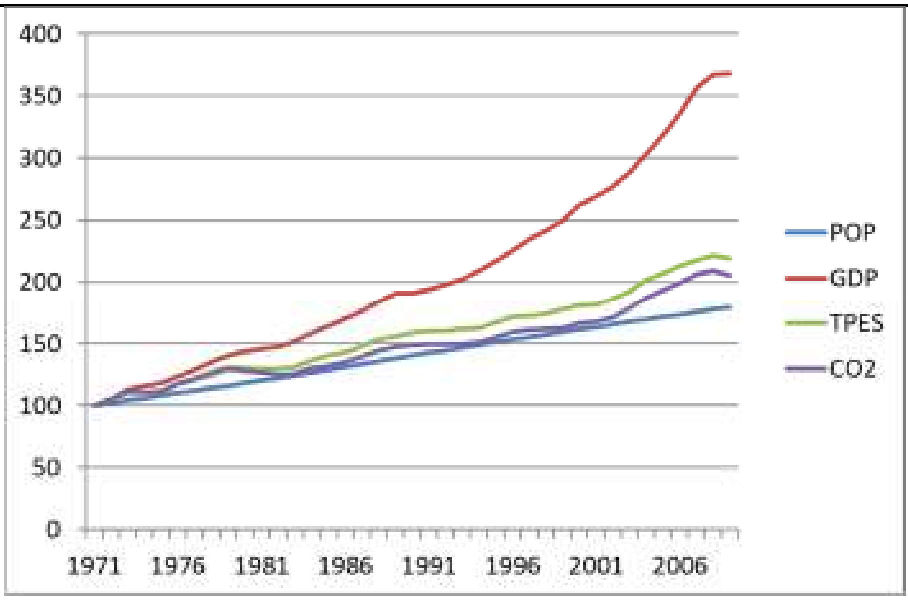

Figure 1. Trends of basic ImPACT variables in the World, years 1971-2009 (index, 1971=100).

Fig. 2 shows that in China, the situation is similar to the World as a whole but the GDP growth has been extremely fast and there is a weak decoupling between GDP and CO_2 emissions from fuel combustion. Growth in primary energy use (TPES) has been relatively modest but increased especially in the 2000s, which indicates that the use of fossil fuels, coal in particular, has increased a lot in China during the last two decades (Fig 2). In the most recent years, there has also been a rapid growth in renewable energy but this is not visible in Fig. 2, Population growth has been controlled with the one child policy during the years 1979-2015, i.e. during almost the whole study period.

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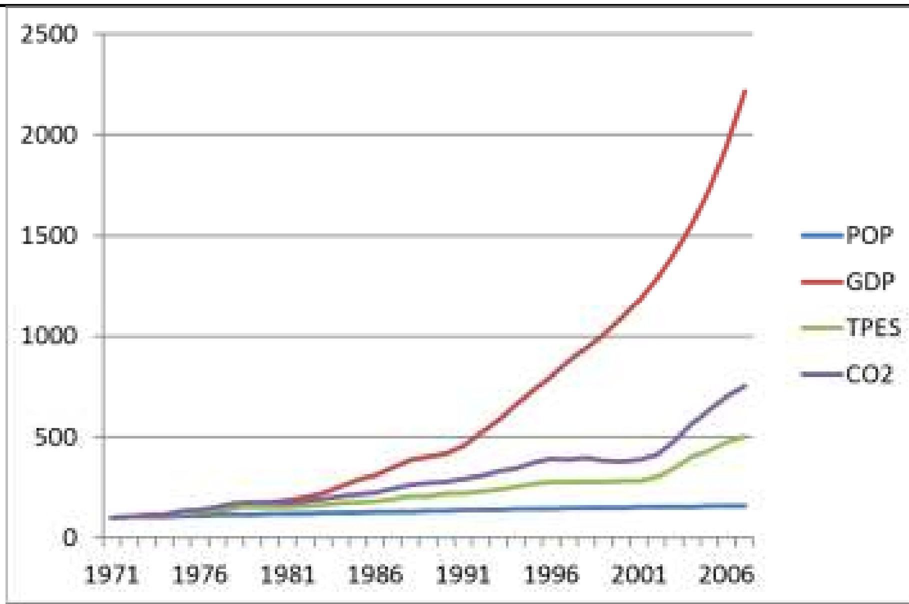
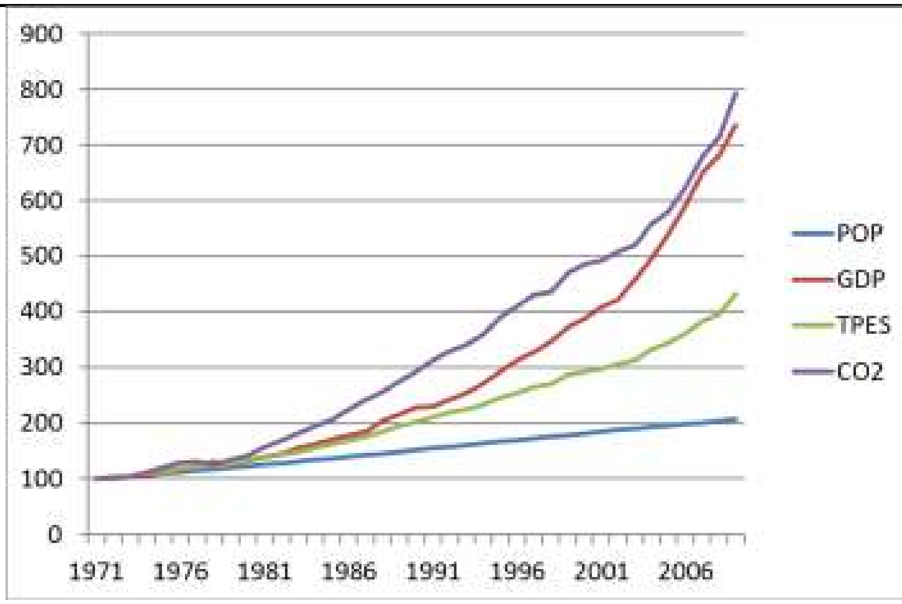
Figure 2. Trends of basic ImPACT variables in China, years 1971-2009 (index, 1971=100).



In India, it is remarkable that the growth in CO_2 emissions from fuel combustion has been even faster than the growth of GDP during the 2000s (Fig. 3). Growth in primary energy use (TPES) has been relatively modest when compared to growth in CO_2 emissions or in GDP, which means that the use of fossil fuels has been increased and caused also an increase in carbon intensity of the economy during the recent years. Thus, there is no sign of any decoupling between CO_2 emissions and GDP in India. Population growth has been much slower than the growth in other basic variables in all cases, and in India, it has been slightly faster than in China (Fig. 2 and Fig. 3).

Figure 3. Trends of basic ImPACT variables in India, years 1971-2009 (index, 1971=100).



In the following, comparisons between China, India, and the World as a whole will be made by using the three-year moving average values of logarithmic ImPACT variables presented in Equations 4-8. The moving average logarithmic values can be considered as estimates of annual change rates of the ImPACT variables; i.e. average annual change rates of impact (CO_2; Fig. 4), population (POP; Fig. 5), affluence (GDP/POP; Fig. 6), consumption (TPES/GDP; Fig. 7), and technology (CO_2/TPES; Fig. 8) during the study period 1971-2009. On the basis of the logarithmic function presented above, when the multiplied PACT variables equal to the I variable, the sum of logarithmic pact variables sum up to the logarithmic i variable.

Fig. 4 shows the estimated change rate of environmental impact, in this analysis CO_2 emissions from fuel combustion in the World, China, and India. Globally, CO_2 emissions have mostly increased, but the rate has been lower than in China and India, except during the recession and the late 1990s. In China, the annual growth rate has varied in a larger scale than in India, but in both large developing countries CO_2 emissions have increased rapidly, typically 4-8 per cent annually. In China, in 1976 and in 2004 the estimated growth rate of CO_2 emissions from fuel combustion has exceeded 10 %.

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Figure 4. Annual changes in the logarithmic values of CO2 emissions in the World, China and India, 1971-2009.

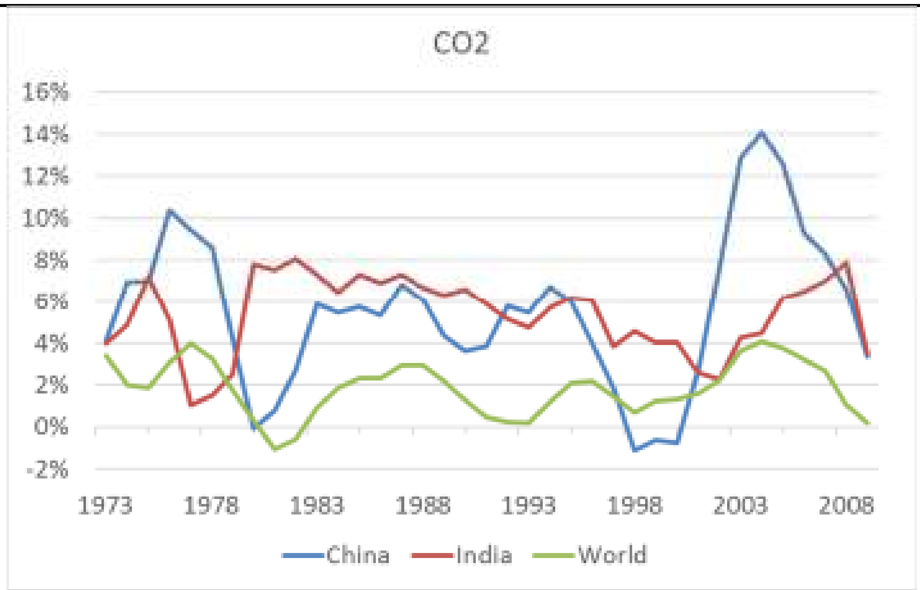

Fig. 5 shows that the population growth rate has been higher in India than in China and the World on average. Due to the Chinese "one child policy, population growth rate decreased rapidly in China, being well below the global rate since the early 1970s. However, although the population growth rate has decreased globally, also in India, the World population is still growing over one per cent each year.

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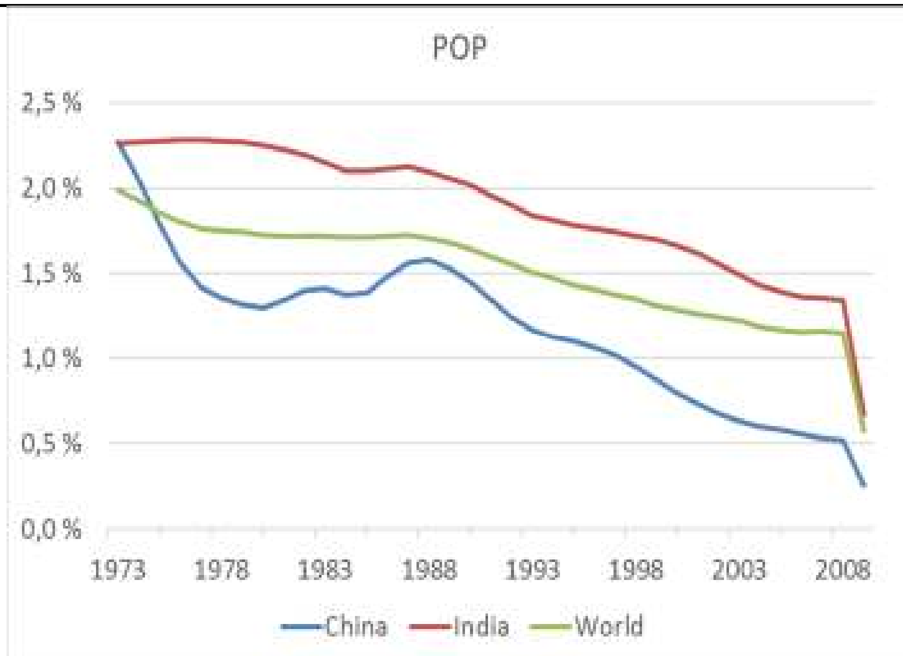
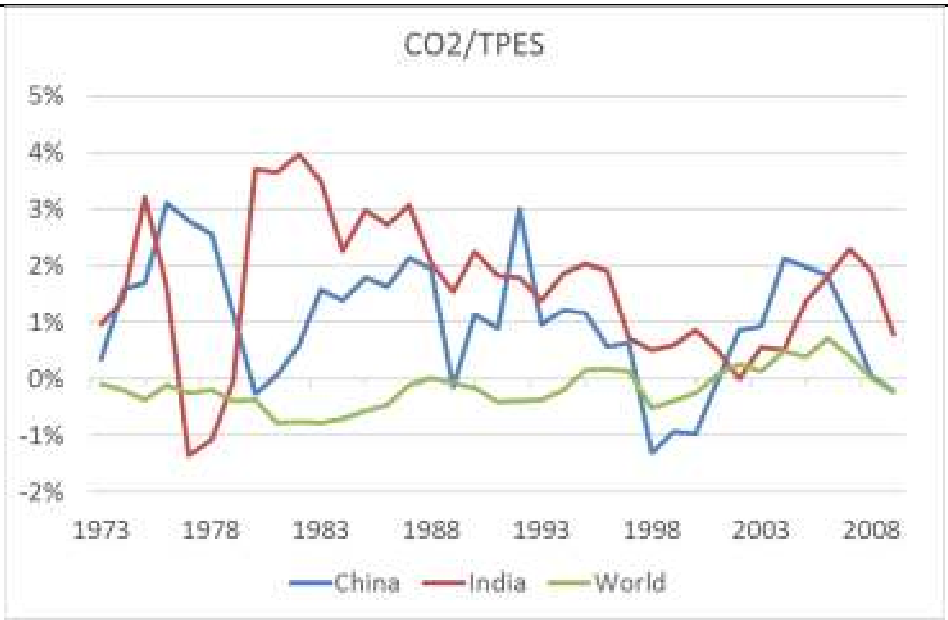


Figure 5. Annual changes in the logarithmic values of population in the World, China and India, 1971-2009.

In Fig. 6, the change rate of carbon intensity of primary energy use (CO_2/TPES) is presented for China, India, and the World. When, for example, a fuel switch from fossil fuels to renewables – or vice versa – takes place, carbon intensity changes. Key observation from Fig. 6 is that there has been quite a large variation in annual change rates in carbon intensity of primary energy use, both in China and India. In general, industrialization via globalization has led the economies of these two large developing countries to higher level of carbon intensity. At the same time, carbon intensity of primary energy use of the industrial countries in Western economies has decreased, and thus there has not been any significant change in the carbon intensity at the global level (Fig. 6).

Figure 6. Annual changes in the logarithmic values of CO2/TPES in the World, China and India, 1971-2009.



Annual changes in TPES/GDP in the World, China, and India are reported in Fig.7. TPES/GDP describes the overall energy intensity of the national economy in terms of primary energy use. In general, energy intensity is affected by the stage of economic development and industrial structure of the country, as well as climatic and geographical conditions. Traditionally, energy intensity in developing countries increases through industrialization, but this no longer seems to be the case in China. Annual change in TPES/GDP has been mostly negative in China, with only a couple of positive peaks during the study period 1971-2009. Change of TPES/GDP in India and in the World has been very similar. As noted by several authors, China has had quite a good trend of change in energy intensity (Kaivo-oja et al, 2014). The reasons for this cannot be analyzed deeply here, but the rapid economic growth is a major explanation, because it has been faster than increase in primary energy use. This also reflects a structural change from energy intensive primary industries to lighter industries and services. Another major explanation is the increasing efficiency of the entire energy system. This includes e.g. increasing use of new and more efficient energy technologies (Kaivo-oja et al, 2014; cf. Williams, 1992).

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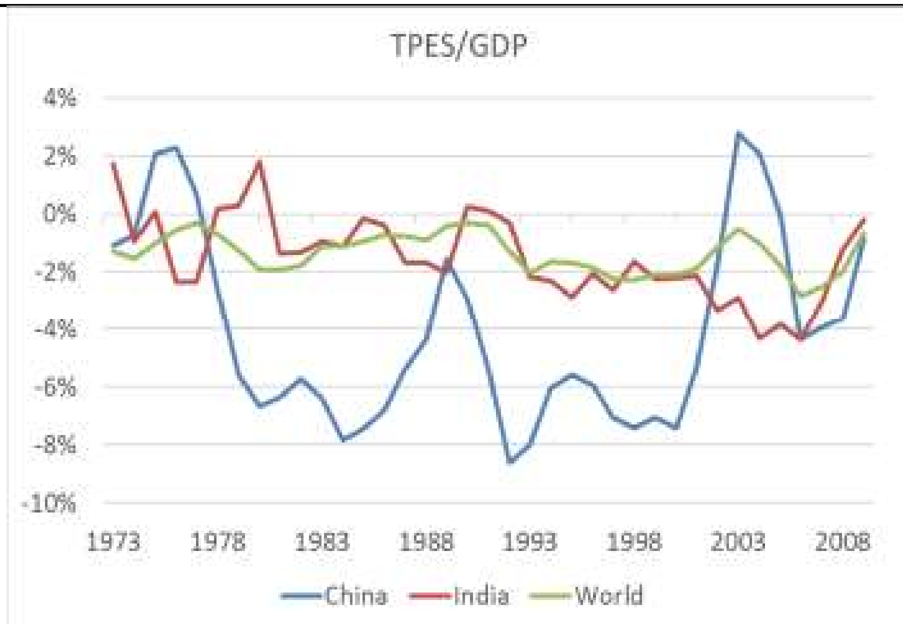
Figure 7. Annual changes in the logarithmic values of TPES/GDP in the World, China and India, 1971-2009.



Change rate in gross domestic product per capita (GDP/POP) in China, India, and the World is shown in Fig. 8. Economic growth has been quite fast in the two major developing countries. Especially in China the annual growth rate has in some years exceeded 10 % which is clearly higher than in India or in the World as a whole. This reflects the rapid development within the country, which is partly due to active Chinese economic policies, but also a result of global division of labour and increasing foreign investments.

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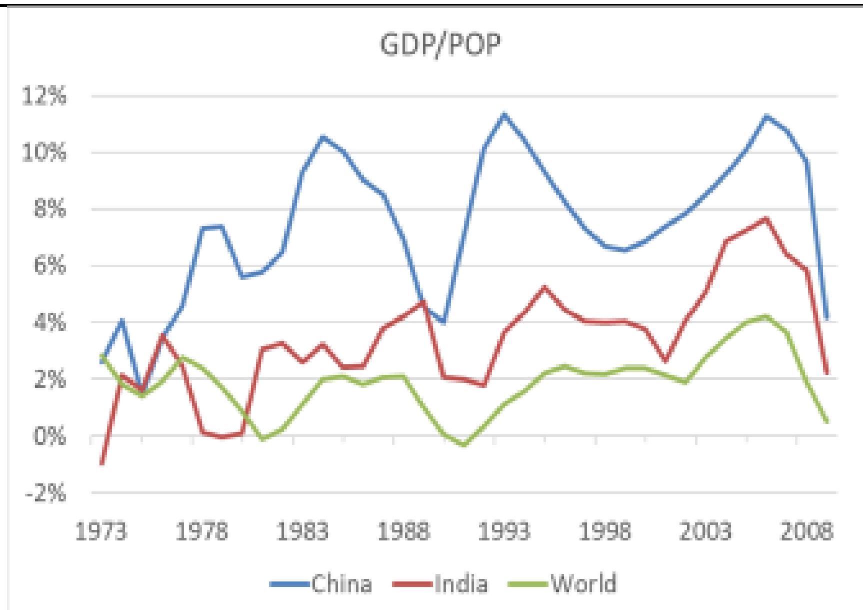
Figure 8. Annual changes in the logarithmic values of GDP/POP in the World, China and India, 1971-2009.



Identification of ImPACT Cycles in the World, China and India

In this section, a cyclical nature of sustainable development will be identified by applying the drivers of the ImPACT identity presented earlier in this paper: population (POP), affluence (GDP/POP), consumption (TPES/GDP), and technology (CO_2/TPES). A simple framework for this will be first outlined. This framework allows us to make preliminary interpretations of the historical sustainability trends.

In Fig.9, four different sustainability zones have been identified, depending on the direction of change in the ImPACT drivers of CO_2 emissions. Drivers have been divided into two categories; (i) drivers which can be "easily" affected by policy measures aiming at decreasing CO_2 emissions and (ii) drivers which cannot be easily affected by policy measures. In the ImPACT framework, the first category includes consumption (c) and technology (t), and the second category includes population (p) and affluence (a). Thus, the sum of annual changes in the first category (c+t) is on the vertical axis and the second category (p+a) on the horizontal axis. Both categories are operationalized with logarithmic estimates of annual change rates, which can be summed as Equation 2 above shows. Following this logic, the only "sustainable" zone is the one where the sum of change rates in population (POP) and

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affluence (GDP/POP), marked as p+a, is positive, and the sum of change rates in consumption (TPES/GDP) and technology (CO_2/TPES), marked as c+t, is negative. As shown earlier, the sum of change rates mathematically equals to the change rate of CO_2 emissions from fuel combustion, due to the nature of the logarithmic function.

The idea is that sustainable ways to reduce CO_2 emissions include decreasing consumption (TPES/GDP) and improving technology (CO_2/TPES) in a way that the sum of the change CO_2 emissions, caused by these two drivers, is negative. Decreasing the amount of population or decreasing the affluence of that population, although they would decrease CO_2 emissions, are not considered as sustainable solutions, because they may violate the social and economic perspectives to sustainable development. However, in other approaches, such as degrowth, the choices may be different,.

The opposite area, where p+a is negative and c+t positive, is a totally unsustainable zone. The other zones are semi-sustainable in the sense that development is controversial, either in terms of population and economy (p+a), or in terms of consumption and technology (c+t). This approach enables also a definition of weak and strong sustainability. Strong sustainability requires that the total sum (c+t)+(p+a) is negative, i.e. the decreasing effect of consumption and technology (c+t) overrides the increasing effect of population and affluence (p+a) in terms of driving CO_2 emissions.

Figure 9. Sustainability zones in the ImPACT analysis.

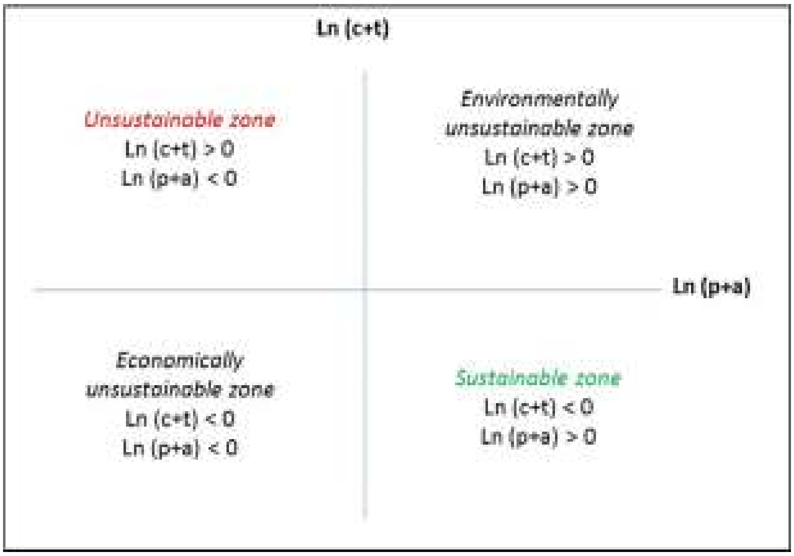

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Fig.10 shows the c+t and p+a changes plotted for the World. Three year moving averages have been used to smoothen the data for bringing out a cyclical nature between the "increasing" (p+a) and "decreasing" (c+t) driver combinations affecting change in CO_2 emissions from fuel combustion. The cycle of two sum variables (p+a and c+t) resembles Goodwin's growth cycle (Goodwin, 1967, 1990; Goodwin & Punzo, 1987; Flaschel, 2010). Thus, there are certain macrodynamic phenomena of capitalism, as Flaschel (2010) has presented in his book "The Macrodynamics of Capitalism". There is a possibility that a sustainability cycle also follows a general cyclical macrodynamic logic of capitalistic development. During the sustainability cycle, economies travel through different zones of sustainability over time. Our study indicates this kind of cyclical logic of the key ImPACT drivers.

This kind of finding is quite interesting and reminds that sustainable development has a complex nature which is still poorly understood. Probably the cycles of sustainability should be taken seriously in global sustainability and development policies and planning. This might be important for the so-called green growth strategies (see UNEP, 2011; OECD, 2013). Thinking is probably too linear as regards global sustainability challenges. In the future, sustainability cycles should be analyzed carefully and taken into consideration when new policy platforms and social innovations are presented.

Fig. 10 shows the World's development from the ImPACT perspective, highlighting a long-run cycle instead of a linear trend towards sustainability (or away from it). The annual change rate of c+t has been negative, and the annual change rate of p+a has been positive during the whole study period. However, the rate and volatility of p+a has been higher than volatility of c+t. One key explaining factor of this kind of cycle is that the effects of investments have time lags. In terms of absolute values, (positive) change rates of p+a have been higher than the (negative) change rates of c+t, so there is a specific cyclical trend towards sustainability at the global level with the indicators used here, but not a strong one. Strong sustainability would require that the absolute value of (negative) change rate of c+t is larger than the absolute value of (positive) change rate of p+a.

Figure 10. Cycle of annual change rates of population and affluence (p+a) and consumption and technology (p+t) in the World, three-year moving averages of logarithmic values 1971-2009.

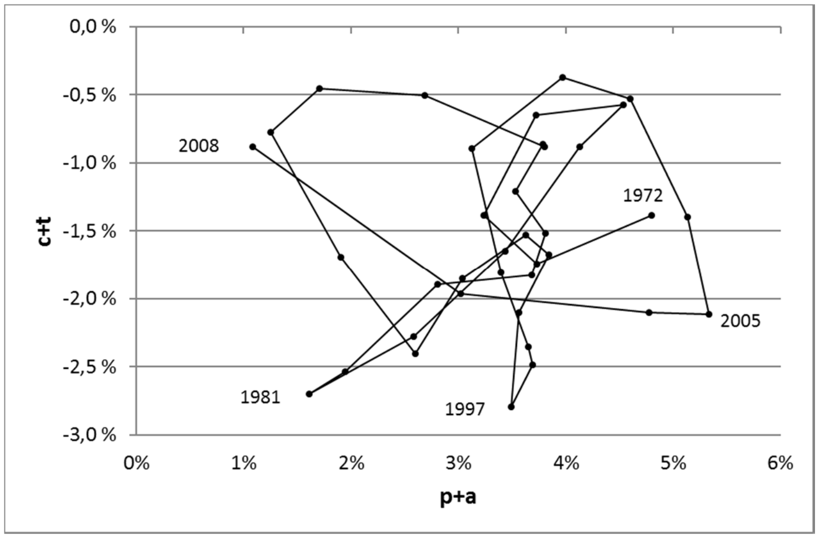

Fig. 11 describes the cyclical sustainability trend in China. The annual change rate of c+t has been positive during the periods 1972-1976 and 2002-2005, but negative during the rest of the study period 1971-2009. Volatility in change rate p+a has been somewhat higher than the volatility in change rate c+t, and the absolute values of change rate p+a have been usually higher than the absolute values of change rate c+t. In China, there has been a weak trend towards sustainability after 2005, but in general, China has performed poorer than the World as a whole.

Figure 11. Cycle of annual change rates of population and affluence (p+a) and consumption and technology (p+t) in China, three-year moving averages of logarithmic values 1971-2009.

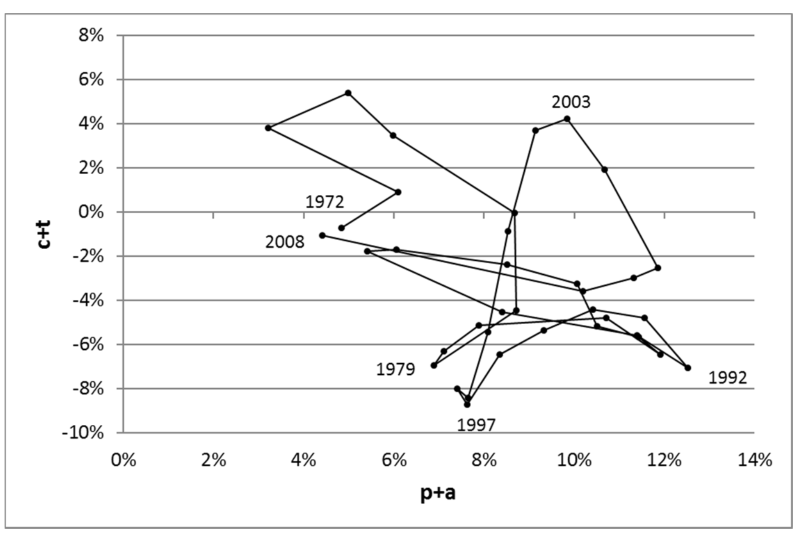

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Fig. 12 illustrates the cyclical development of c+t and p+a in India. Annual percentage changes of c+t have been both positive and negative. As in China, also in India the volatility of p+a has been higher than the volatility of c+t. The absolute values of annual change rates in c+t have always been smaller than the absolute values of change rates of p+a, so India does not have any signs of strong sustainability, and weak sustainability only during the periods where annual change rate of c+t has been negative. India's sustainability cycle has been more in the unsustainable zone than the one of China. In terms of the sustainability cycles identified in this paper, both India and China have more unsustainable cyclical trends than the World as a whole.

Figure 12. Cycle of annual change rates of population and affluence (p+a) and consumption and technology (p+t) in India, three-year moving averages of logarithmic values 1971-2009.

A major empirical result of the simple analysis of "decreasing" drivers (consumption; TPES/GDP and technology; CO_2/TPES) and "increasing" drivers (population; POP and affluence; GDP/POP) of the ImPACT identity applied to CO_2 emissions from fuel combustion in Fig. 11 and Fig.12 is that the large developing countries China and India seem to follow some kind of a cyclical trend. Whether it is towards sustainability of away from it, depends on the time period. Both countries have been in the sustainable zone, China more often than India. Compared to the World as a whole (Figs. 10-12), both China and India have not performed very well. However, although the World has been in the sustainability zone during the whole study period 1971-2009, strong sustainability has taken place only in the context of the so-called second oil crisis. At that time, the absolute value of (negative) change rate of c+t has been larger than the absolute value of change rate of p+a, which is the criterion for strong sustainability in the applied ImPACT framework.

Discussion and Conclusions

The contribution of this paper in relation to previous literature is to present the ImPACT identity in such a form that makes it possible to observe the dynamics of sustainability in a four-space mapping framework. This may help to identify "danger zones" of unsustainable development from less dangerous sustainability zones. Some interesting observations about development over time can be made and some turning points in history identified. The World scale and country level analyses of China and India reveal that after the 1970s, these large developing countries have been in the unsustainable zone. The socio-economic conditions of sustainability policy also vary over time.

In this paper the key variables of the ImPACT identity on carbon dioxide emissions from duel combustion have been studied, and annual change rates of ImPACT drivers (p, a, c, and t) have been defined and operationalized by applying a logarithmic function to the ImPACT identity defined in Equation 1. The ImPACT drivers have been divided into two categories depending on their possibilities to be affected by policies aiming at decreasing carbon dioxide emissions from fuel combustion (CO_2). The four ImPACT drivers of CO_2 include two non-policy drivers (population; POP and affluence; GDP/POP) and two policy drivers (consumption; TPES/GDP and technology; CO_2/TPES). For global policy development change of these critical drivers is very important. In this paper, the long-run ImPACT driver cycles in the World, China, and India have been identified and related novel results based on the affluence-population dimension and consumption-technology dimension have been reported. The empirical analysis revealed that the volatility of non-policy drivers (p+a) is stronger than the volatility of policy drivers (c+t). The sustainability cycles for China, India, and the World have been identified. These cycles may have a logic similar to Goodwin's growth cycle model, but with ImPACT drivers. This observation is interesting for further research of sustainability challenges (cf. Goodwin, 1990; see UNEP, 2011; OECD, 2013).

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The issue of sustainability cycle requires more research, as this paper only brings the issue into discussion without any deeper analysis. Sustainability cycle potential to be paid attention to in World politics and sectoral policies dealing with environment and development at national level. The identified sustainability cycles are different, so the conclusion is that there probably is no linear or simple path or so-called "sustainability tunnel" regarding CO_2 emissions from fuel combustion for big countries such as China and India. This means that the challenges of global governance include sustainability management of giant rapidly growing economies such as China and India. The study presented in this paper serves such political needs, and the potential smart shaping of sustainability strategies in the globalized World. Development towards a low-carbon economy is not a linear but rather a cyclical one, due to the system dynamics and time lags in the global economic system. Analysis of the sustainability cycles and their differences between China and India, applying the presented approach to other countries, also to Western economies, as well as development of a sustainability cycle model for empirical testing are obvious topics for further research.

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